Study of Automatic Electric Fire Pumps

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A study of automatic
electric fire pumps

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A STUDY

of

AUTOMATIC ELECTRIC FIRE PUMPS

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A T H E S I S

presented

by

L. R. Ross

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to the

PRESIDENT AND FACULTY

of

ARMOUR INSTITUTE OF TECHNOLOGY

for the degree of

BACHELOR OF SCIENCE IN FIRE PROTECTION ENGINEERING

having completed

the prescribed course of study in

FIRE PROTECTION ENGINEERING

June 1, 1906.

Approved: Arthur R. Taylor - Prof. Fire Protection Engineering

Howard M. Raymond

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A STUDY OF AUTOMATIC ELECTRIC FIRE PUMPS.

The needless destruction of life and property each year, by fire, is gradually educating the people to the necessity of building correctly and of equipping such buildings with the proper protective apparatus. Thus it is that private pumping machinery is comming into more and more general use, especially in outlying districts and where the public water supply is of the low pressure type. In order that automatic sprinklers and private yard mains and equipments may give the most satisfactory results, it is necessary; first, that an abundant supply of water be on hand at all times; second, that it may be supplied instantly; third, that the head be sufficient for good working conditions. A gravity system, although usually fulfilling the latter two conditions, is rarely able to meet the first. Probably the method which would most satisfactorily fulfil the above three requirements is the use of automatically controlled pumps.

It is the object of this thesis to familiarize the writers with the various parts of automatic electric fire pump equipments, and to derive a formula for the minimum size of air tank permissable for a given installation.

The air tank for any given pump and controller should be as small as possible, and still perform its functions properly, because the cost of such a tank increases much more rapidly than the size. If, however, the air cushion be too small, the pump will be required to start and stop so frequently

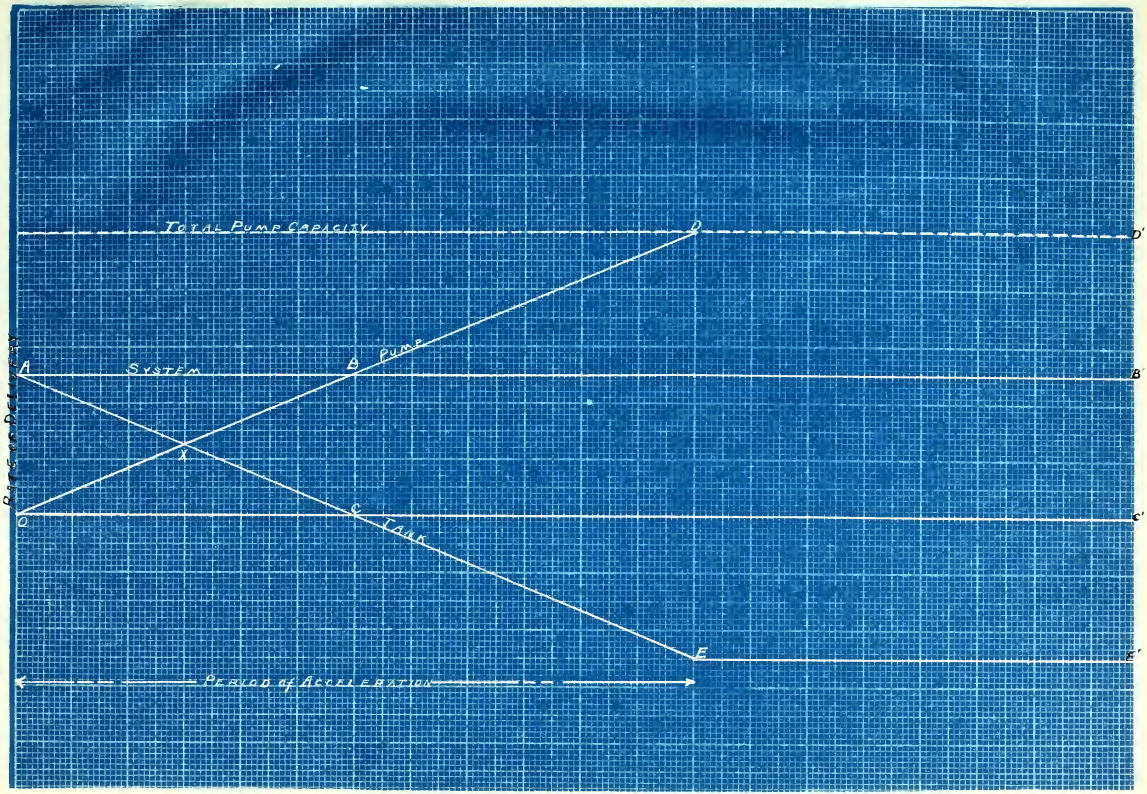
as to overheat the resistances of the controller. The size of pressure tank must therefore, be properly proportioned to the time elements of the controller. The necessity for a formula, such as we have attempted to derive, is therefore evident.

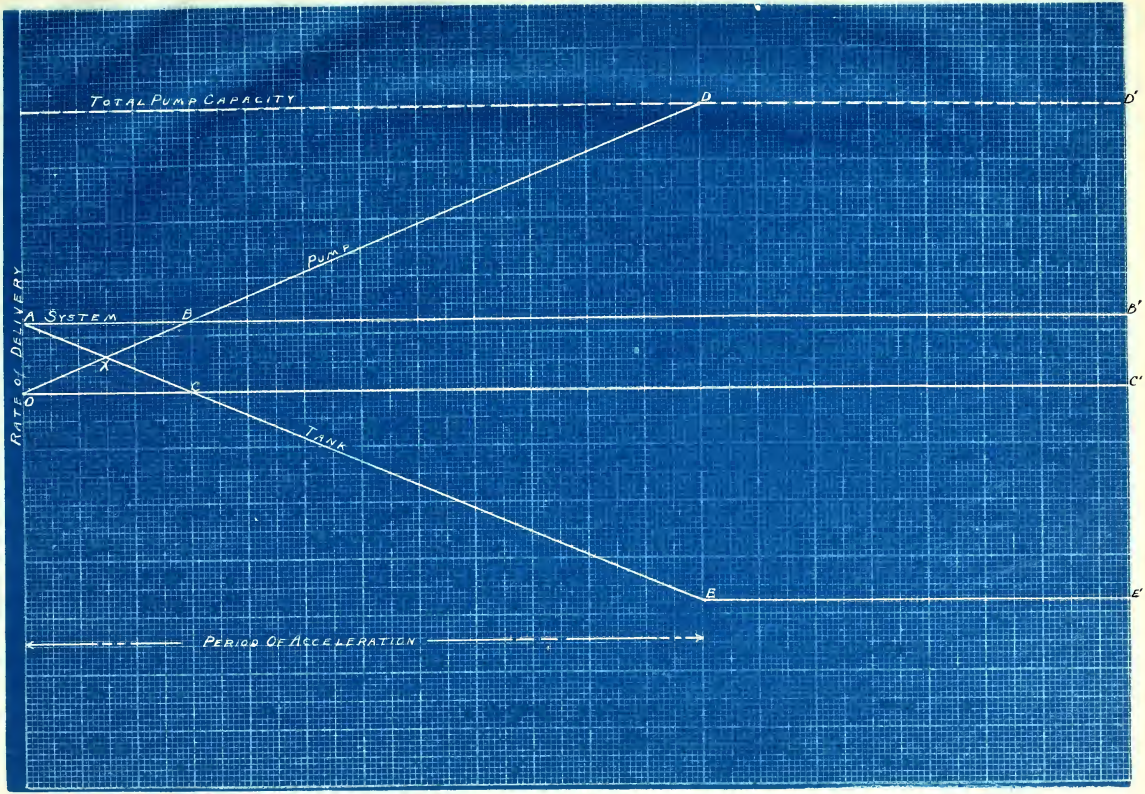
The parts entering into an automatic electric fire pump equipment are, an electrically driven pump, an air or pressure tank, a controller for starting and stopping the pump, and an adjustable pressure regulator which throws the controller in and out of service when the pressure in the tank has reached the proper points. The pressure tank is connected directly to the main into which the pump discharges, thus keeping the pressure in the system equal to that in the tank. The pressure regulator is connected directly to the pressure tank by means of a small pipe, so that the pressure of the system can act upon it. This regulator is so made that when the pressure in the system drops to a certain point, an electrical contact is made thus bringing the pump into service by means of the controller. The maximum pressure for which it is set throws the controller out of service and thus stops the pump.

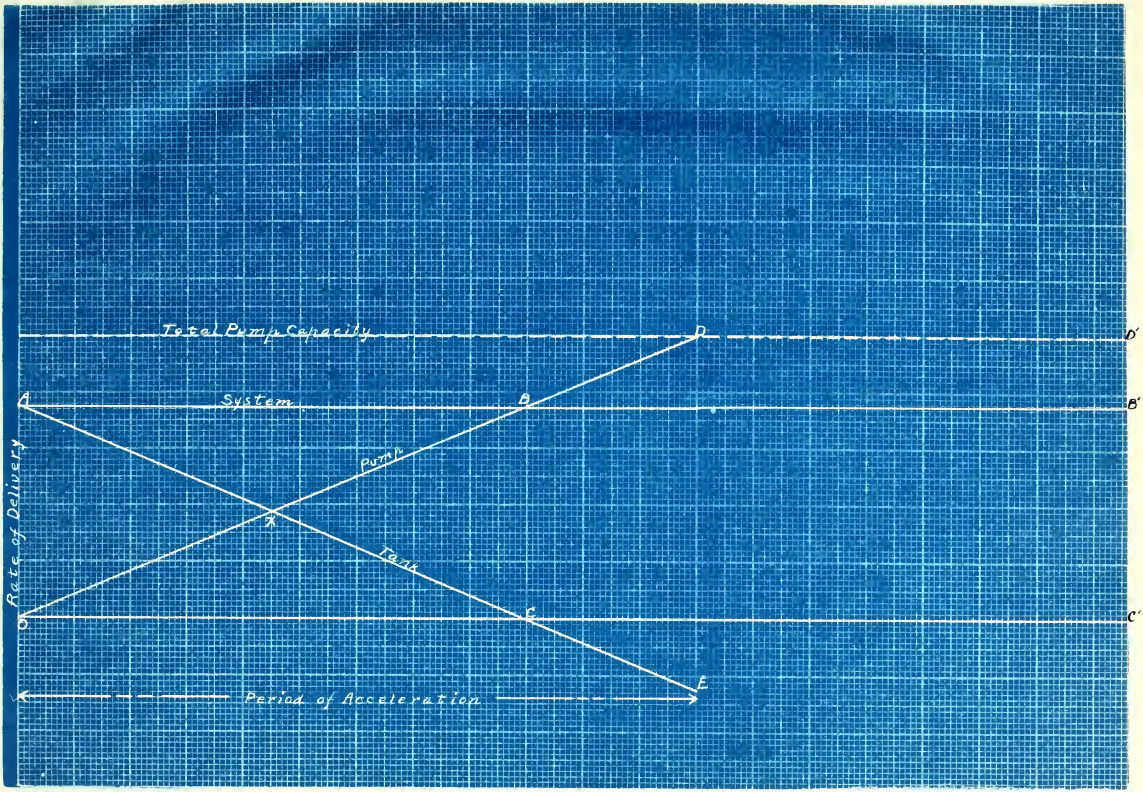
The action of such an equipment can be described as follows:- When the system is first called upon for water, the pressure tank will furnish the demand, till the pressure in the tank has reached the cutting-in point for which the controller is set. The pump then starts but does not reach full speed immediately but gradually accelerates. In the mean time the discharge from the system is nearly constant,

consequently until the pump acquires sufficient speed to furnish the demand, the tank will continue to furnish some water to the system. As the pump speeds up, it discharges more and more water to the system, the tank in the meantime supplying less and less; at some intermediate speed, the pump will overpower the tank and supply the system alone. Beyond this point the pump discharges the surplus into the tank, compressing the air until the pressure is raised to that at which the controller is set to cut out, the pump in the meantime having reached full speed. After the pump is cut out, the tank again supplies the discharge and the cycle has been completed.

Three cases are graphically illustrated, on the following blue prints, showing the relations existing between tank and pump discharges, for as many rates of discharge from the system. In the first case, we will consider the conditions when the discharge from the system equals one-half the capacity of the pump. This discharge is constant and is represented on the first curve sheet by line ABB', while the total pump capacity is represented by a line of double the ordinate of ABB', at DD'. At the beginning of a cycle, the pump starts and begins to take up a part of the load; in the present discussion we will assume that the acceleration is uniform. Just as the pump starts the tank is supplying the entire demand on the system, but as the pump speeds up it assumes the load and the work done by the tank is decreased. The work done by the pump, during the acceleration period, is shown by the line OXBD, and that by the tank, by the line


TOTAL PUMP CAPACITY
D
D'
A
SYSTEM
B
PUMP
B'
X
RATE OF DELIVERY
O
C
TANK
C'
E
E'
PERIOD of ACCELERATION


TOTAL PUMP CAPACITY
D
D'
PUMP
RATE OF DELIVERY
A SYSTEM
B
B'
X
O
C
C'
TANK
E
E'
PERIOD OF ACCELERATION


Total Pump Capacity
D
D'
A
System
B
B'
Pump
Tank
Rate of Delivery
O
C
C'
E
Period of Acceleration

AXCE. In this case, when the pump has reached half speed, it maintains the system discharge and after that begins to charge the tank. At the end of the acceleration period, D, the tank discharge is a maximum and so remains till the tank pressure is raised to the cutting-out point. In cases two and three the general action of the system is represented respectively for system discharges of one-quarter and three-quarters the pump capacity. The graphical solutions are shown by the second and third curve sheets.

It will be shown that the total period is a minimum when the system is discharging at a rate equal to half the capacity of the pump.

When the system discharge is equal to half the capacity of the pump, the periods of run and rest will be practically equal. This is true because at full speed the pump delivers half the water to the tank and half to the outlets. Since the periods of run and rest are nearly equal we can represent the time of each by 1. The total period of the controller can then be represented by 2.

In the second case under consideration, the system discharge equals one-fourth the pump capacity. The pump then delivers three-quarters of its capacity to the tank or one-quarter more than before. It is evident that the same amount of water as before is required to raise the pressure in the tank from the cutting-in to the cutting-out point, regardless of the rate of delivery. As the rate of delivery to the tank is now three-halves as great as in the first case, the cutt-

ing out point will be reached in two-thirds the time. After the pump has stopped, the tank must discharge the same amount of water as in the previous case, but at half the rate, requiring twice the previous discharge period. In this case the total period will be 2-2/3 as compared with 2 in the first.

In the third case, the system discharge is increased to three-quarters of the pump capacity. The pump will then deliver one-fourth of its rated capacity to the tank, or one-fourth more than in the first case considered. Since, however, the same amount of water as before is required to vary the tank pressure between the same limits, regardless of the rate of delivery, and as the rate of delivery to the tank is now one-half as great as in the first case, it follows that the running period is twice as long. After the pump has stopped the tank must discharge the same quantity as before but at three-halves the rate, requiring two-thirds the discharge period of case one. Thus the period of operation of the controller is 2-2/3 as compared with 2 in the first case.

These three cases are sufficient to show that the minimum controller period occurs when the discharge from the system is one-half the pump capacity.

When the system discharge equals one-half the pump capacity, the pump delivers to the tank one-fourth as much water during the acceleration period as it does in the same time while running at full speed. This is true for the reason that during the first half of the acceleration period the pump delivers no water to the tank,and during the second half

of the controller period it delivers half of its capacity to the tank and half to the outlets. Thus it will be seen that the amount of water delivered to the tank during the acceleration period, is one-fourth as much as would be delivered if the pump were working at full speed for one-fourth the acceleration period.

Several tests were made on an automatic electric fire pump equipment, at the Underwriters' Laboratories, # 382 E. Ohio St., Chicago, Ill., by the writers. The object of these tests was to note the effect that the rate of discharge had upon the system. The apparatus is especially adapted for test purposes, and may be described as follows:-

The pump is a 500 gallon Quimby screw pump, direct connected to a 50 H. P. compound wound D. C. motor. The pressure tank is constructed of boiler steel, and has a capacity of 4500 gallons. Gauge glasses are provided so that the height of water in the tank can be seen and measured by means of an attached scale, which is calibrated to read in 100 gallon steps.

The pump can be controlled either manually or by an automatic controller. The manual controller is of the ordinary street car type, operating on either 110 or 220 volts, as desired. The purpose of the hand control is to enable the pump to be used when the pressure tank is out of service. The automatic controller is of the Cutler-Hammer Mfg. Co's multiple solenoid self-starter type, and is so constructed that it brings the pump up to full speed gradually. This is accomplished by cutting resistance, in the proper steps, out of the armature circuit by means of brush contact switches operated by solenoids.

The controller is so arranged that a pilot self-starter, of the solenoid type, has its windings connected directly across the main line, thus receiving power as soon as the armature circuit is closed by the pressure regulator. It gradually lifts a lever over a number of contacts at a speed dependent upon the adjustment of the retarding dash-pot. The lever of this self-starter, through the several contacts over which it passes, controls directly the solenoids which in turn control the armature starting resistance, so that as the self-starter lifts, the several solenoid switches lift in succession, thus gradually cutting out the armature starting resistance. As the lever passes on, the resistance solenoids are cut out of service again, so that in the running position of the master solenoid, only the last resistance switch, that is, the switch which short circuits all the starting resistance, remains closed, all the other solenoids which control the resistance sections being out of circuit.

The amount of air cushion in the pressure tank was varied for each of the different runs. The reason for changing the size of air cushion for the various runs, was to note the effect on the different periods of the controller; running, resting, and total, for given discharges. To get, for example, a 1000 gallon air cushion, air was pumped into the pressure tank, by means of a Christensen air compressor, when it contained about 100 gallons of water. When a pressure of about 15# was obtained, the air compressor was stopped and the pump started. As the tank filled with water, the air cushion was decreased in size and the pressure increased. In most of the runs, the controll-

ing gauge was set so that cut-out occured at 105# pressure, consequently it was at that pressure that the required volume of air was desired. Starting with an initial pressure of 15# made the cutting-out pressure occur with an air cushion of approximately 1100 gallons. The excess volume of air was then slowly drawn off till the cutting-out point occured at the desired volume.

The system was discharged through a meter nozzle, by means of which the rate of discharge could be accurately determined. The nozzle has ten tips, varying in size from 1/2" to 2-1/2" in diameter, by means of which any discharge up to about 2500 gallons per minute can be obtained. The nozzle has a piezometer gauge connection so that the pressure at the base of the nozzle may be determined. By knowing this pressure and the size of tip used, the rate of discharge in gallons per minute can be determined by means of a logarithmic chart.

In each of the runs the discharge was varied from between 30 - 40 gallons per minute, to the maximum capacity of the pump, 450 - 500 gallons per minute. The discharge was regulated by means of the different sized tips and by throttling the pressure with a valve in the discharge pipe. When the desired rate of flow was obtained, the acceleration, running, and resting periods of the controller, were taken by means of a stop watch. To insure accuracy, the controller was allowed to go through three complete cycles of operations, the lengths of the different periods being taken in each case, and the results averaged. The pressure regulator was set so that the cutting-in point was at 90#, for most of the runs, and the cutting-

out point at 105#. This variation of pressure caused a variation in pressure at the nozzle which had to be taken into account. The maximum and minimum pressures for each cycle and the discharge for each pressure were determined. The true discharge was taken as the average of the two. The minimum and maximum tank pressures, for each cycle, were also obtained.

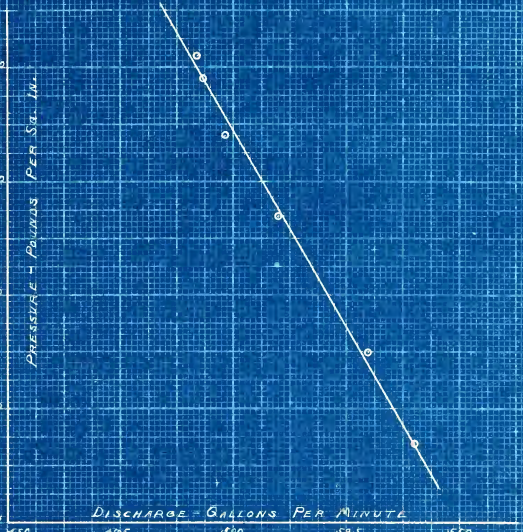
The data was tabulated under the following heads, acc, eleration period, running period, resting period, total period, gallons per minute, minimum pressure and maximum pressure. Curves were plotted showing the relation between the discharge, in gallons per minute and the total, running, and resting periods of the pump; also between the discharge and minimum and maximum pressures. The curves for each log sheet will be found on the blue print immediately following it.

The capacity of the pump, while operating between the minimum and maximum pressures used in obtaining the experimental data, was determined by the use of the meter nozzle. The data was tabulated and it will be found on the following page; the curve showing the discharge graphically, is on the succeeding page.

Calculation Of Formula.

In determining the correct size of pressure tank for a given installation, five factors have to be considered; first, the minimum total period of the controller allowable without overheating; second, the acceleration period of the pump; third the variation in pressure, at heavy discharges, which takes place during the acceleration period of the pump; fourth, the

Pounds Pressure at Pump.	Pump Discharge in Gallons.
109.0	493.0
111.0	492.0
104.0	498.0
97.0	510.0
85.0	530.0
77.0	540.0


PRESSURE - POUNDS PER SQ. IN.
110
100
90
80
70
DISCHARGE - GALLONS PER MINUTE
450
475
500
525
550

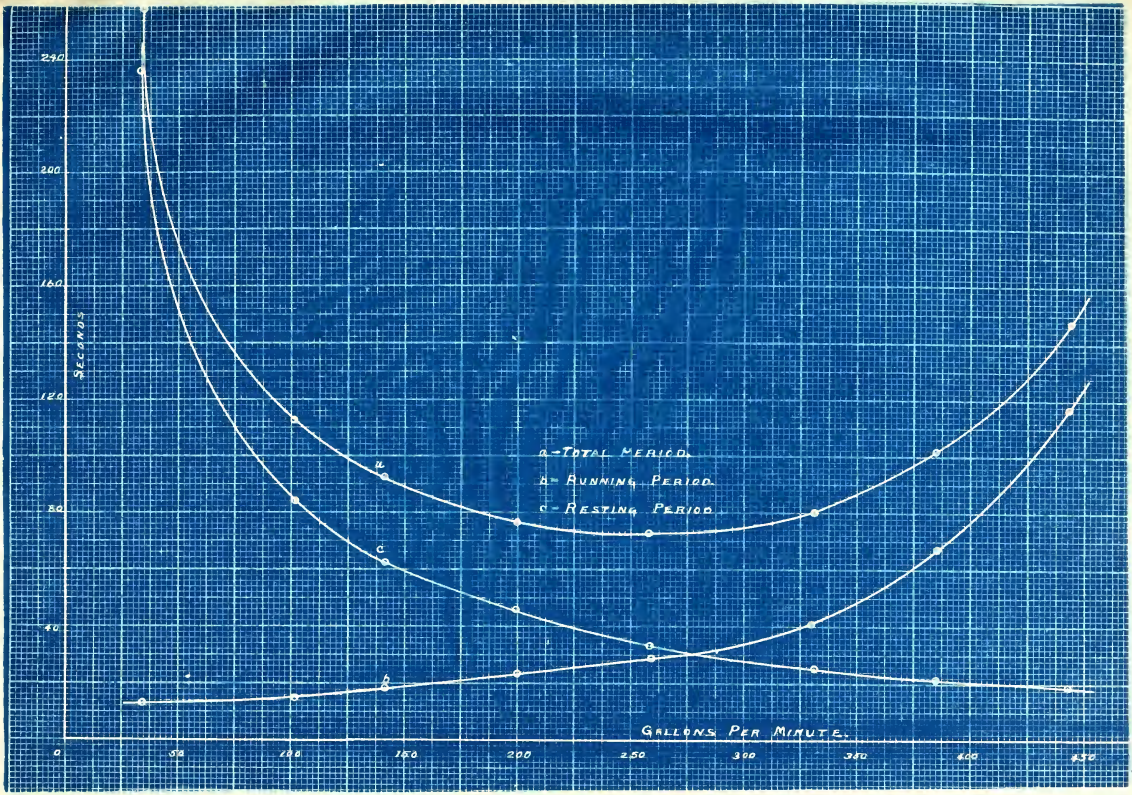
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.
9.2	13.4	253.6	258.4	34.5
13.3	15.0	84.0	112.3	102.0
12.2	18.1	62.1	92.4	141.5
11.5	22.8	42.6	76.9	200.0
12.2	28.6	32.6	73.4	259.5
13.0	41.6	25.3	79.9	331.0
12.7	67.4	21.5	101.6	385.0
12.3	116.4	18.7	147.4	443.0

Air cushion, at cutting out point, 915 gallons.

Air cushion, at cutting in point, 1040 gallons.

Cutting in pressure, 77 pounds.

Cutting out pressure, 96 pounds.


240
200
160
120
80
40
SECONDS
a
b
c
a-TOTAL PERIOD.
b- RUNNING PERIOD.
c- RESTING PERIOD.
GALLONS PER MINUTE.
0
50
100
150
200
250
300
350
400
450

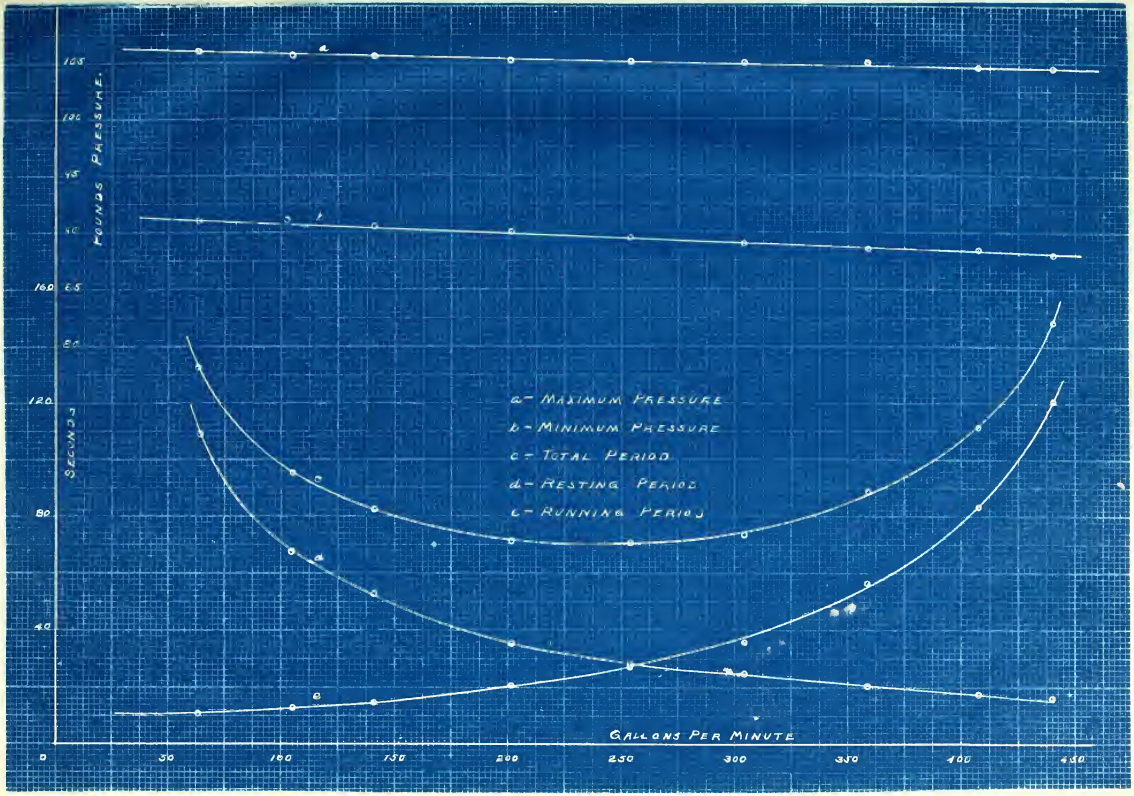
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.	Minimum Pressure.	Maximum Pressure.
14.2	10.8	129.1	154.1	38.4	90.0	105.0
14.9	10.3	108.9	133.1	63.0	90.0	105.0
14.7	12.5	67.9	95.1	105.0	90.0	104.5
14.7	14.7	52.7	82.1	140.5	89.5	104.0
14.9	20.5	35.8	71.2	202.0	89.0	104.0
14.4	27.4	29.0	70.8	253.5	88.5	104.0
13.4	35.9	24.3	73.6	304.0	88.0	104.0
12.0	56.3	20.4	88.7	358.5	87.5	104.0
11.2	82.9	17.2	111.3	407.5	87.5	103.5
11.8	121.0	16.0	148.8	440.0	87.0	103.5

Air cushion at cutting out point, 1114 gallons.

Air cushion at cutting in point, 1252 gallons.

Cutting in pressure, 90 pounds.

Cutting out pressure, 104.5 pounds.


POUNDS PRESSURE.
SECONDS
GALLONS PER MINUTE
a- MAXIMUM PRESSURE
b- MINIMUM PRESSURE
c- TOTAL PERIOD
d- RESTING PERIOD
e- RUNNING PERIOD
0
50
100
150
200
250
300
350
400
450
120
80
40
160

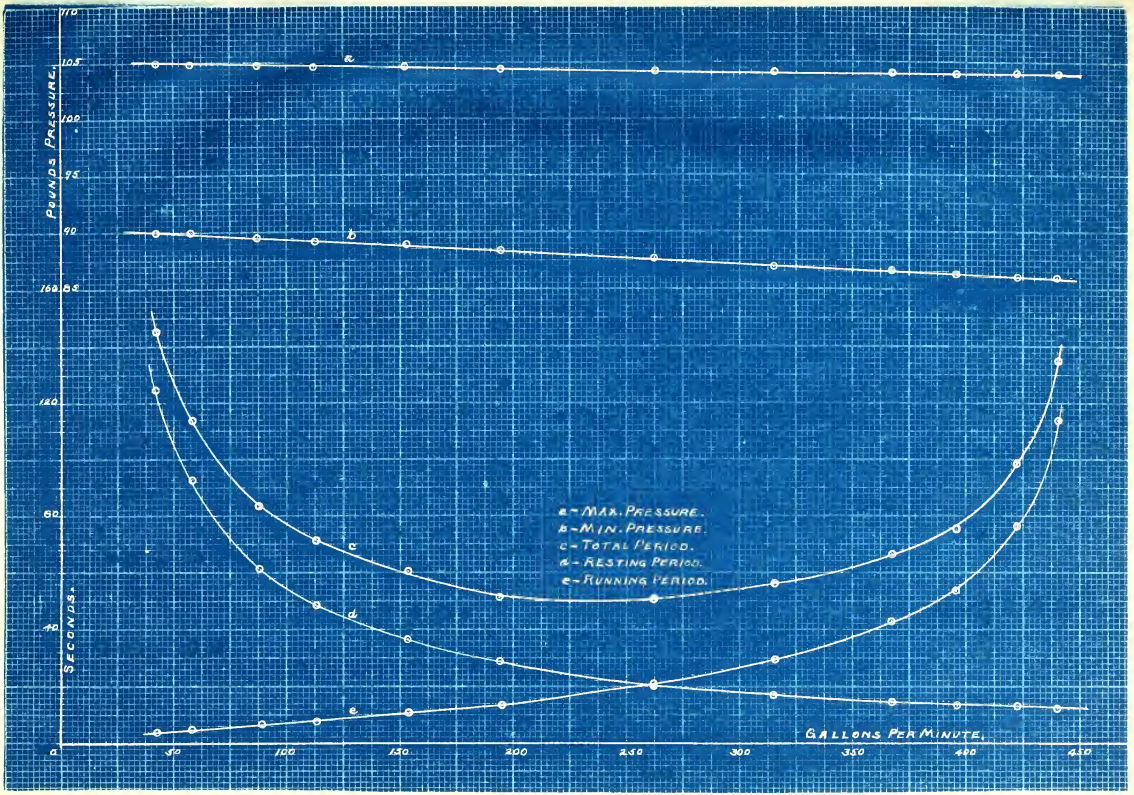
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.	Minimum Pressure.	Maximum Pressure.
16.9	4.0	124.8	145.7	43.5	90.0	105.0
16.3	4.3	93.3	113.9	58.5	90.0	105.0
15.8	6.2	61.0	83.0	89.5	89.5	104.8
15.5	7.6	48.1	71.2	113.0	89.0	104.7
13.7	10.5	36.5	60.7	154.0	89.0	104.6
14.4	13.8	29.0	57.2	194.0	88.5	104.5
9.3	21.3	20.6	51.2	262.5	88.5	104.5
9.0	29.7	17.4	56.1	315.0	88.0	104.4
8.8	43.0	14.4	66.2	367.5	87.0	104.3
8.8	53.0	13.2	75.0	396.0	86.5	104.2
8.5	77.0	13.0	98.5	422.5	86.0	104.0
9.2	114.0	12.3	135.5	440.0	86.0	104.0

Air cushion, at cutting out point, 765 gallons.

Air cushion, at cutting in point, 854 gallons.

Cutting in pressure, 90 pounds.

Cutting out pressure, 105 pounds.


Pounds Pressure.
110
105
100
95
90
85
160
140
60
40
20
0
Seconds.
a
b
c
d
e
a - Max. Pressure.
b - Min. Pressure.
c - Total Period.
d - Resting Period.
e - Running Period.
50
100
150
200
250
300
350
400
450
Gallons Per Minute.

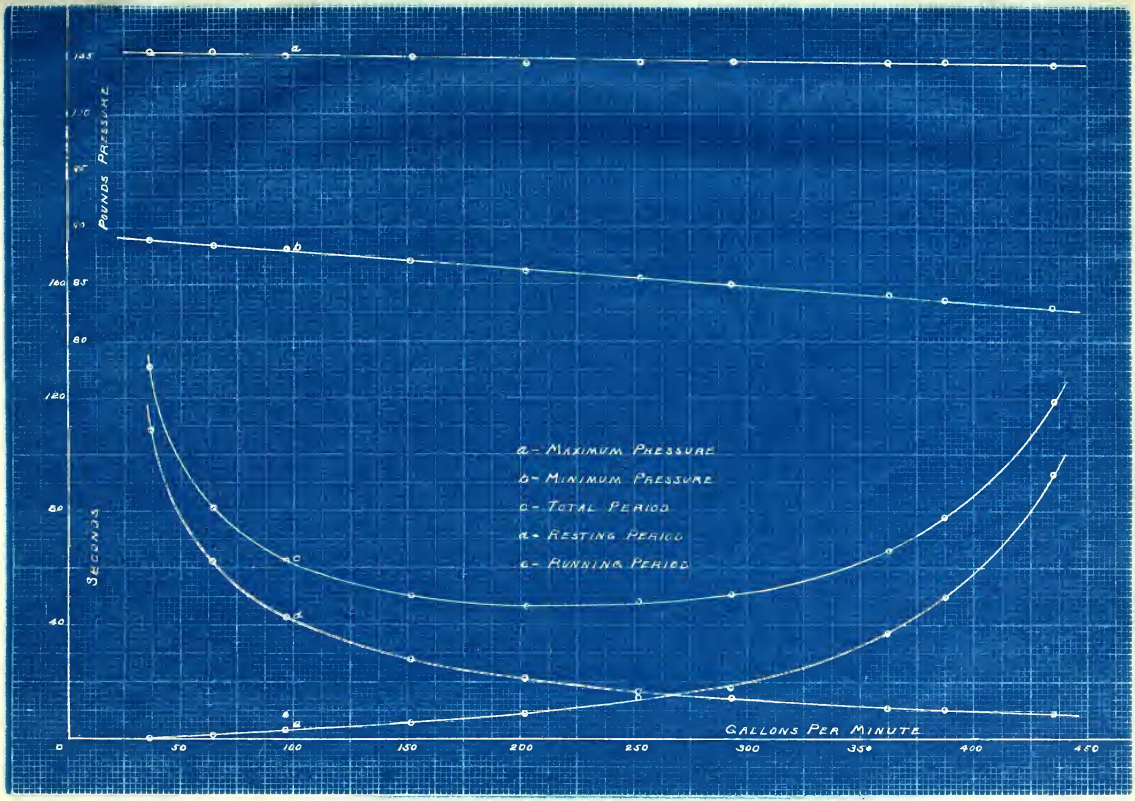
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.	Minimum Pressure.	Maximum Pressure.
18.6	0.0	109.2	127.8	36.8	89.0	105.0
16.8	1.4	62.4	80.6	64.8	88.5	105.5
16.9	2.7	42.8	62;4	97.3	88.0	105.0
17.3	5.7	27.5	50.5	152.0	87;0	105.0
17.3	8.7	20.9	46.9	202.0	86.0	104.5
16.8	14.7	16.7	48.2	252.5	85.5	104.0
16.8	18.6	14.8	50.2	293.0	85.0	104.0
17.9	37.1	11.1	66.1	362.5	84.0	104.0
17.7	49.9	10.4	78.0	387.5	83.5	104.0
16.8	93.3	9.3	119.4	435.0	83.0	104.0

Air cushion, at cutting out point, 527 gallons.

Air cushion, at cutting in point, 611 gallons.

Cutting in pressure, 90.5 pounds.

Cutting out pressure, 105.5 pounds.


Pounds Pressure
Seconds
Gallons Per Minute
a
b
a- Maximum Pressure
b- Minimum Pressure
c- Total Period
d- Resting Period
e- Running Period
0
50
100
150
200
250
300
350
400
450
40
80
120
160
85

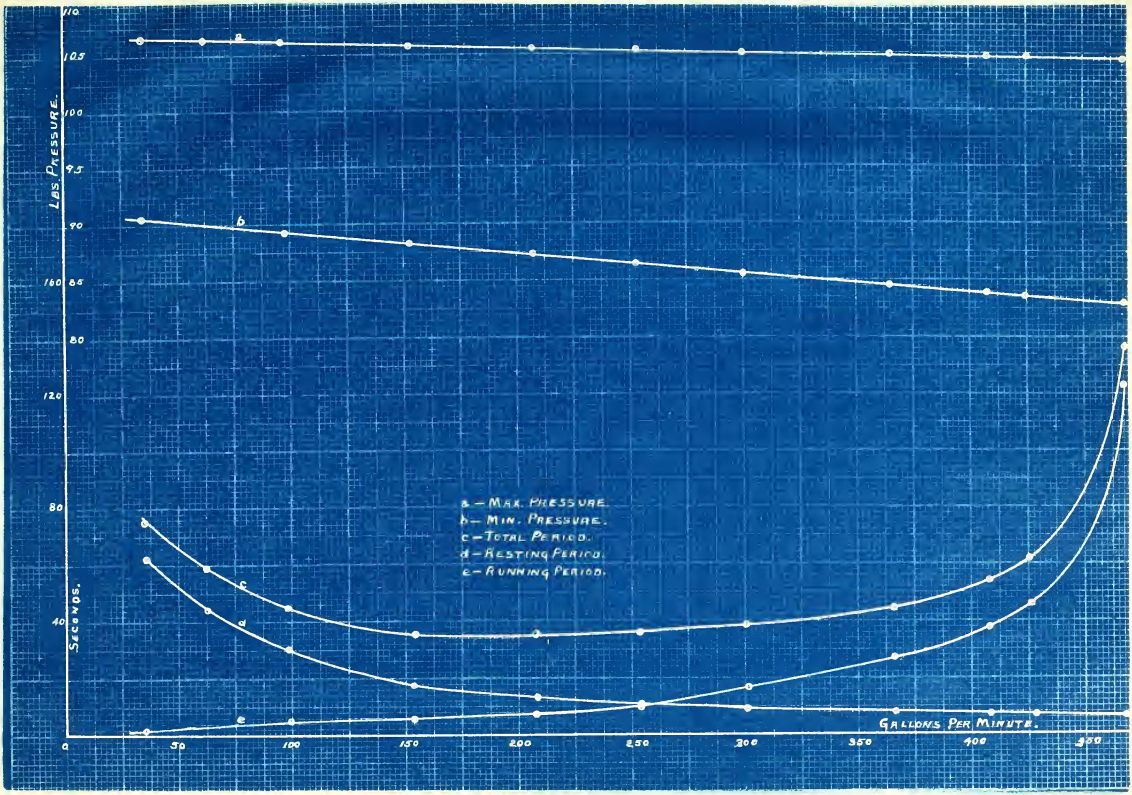
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.	Minimum Pressure.	Maximum Pressure.
13.1	0.3	62.1	75.5	35.5	90.5	106.5
11.7	2.5	45.1	58.4	62.5	90.0	106.5
10.7	4.8	30.0	45.4	99.0	89.0	106.0
13.3	5.5	18.9	35.7	153.0	88.5	105.8
13.3	7.4	14.4	35.1	208.0	87.5	105.5
13.4	10.2	11.9	35.5	253.5	86.5	105.3
13.8	15.8	9.9	38.5	301.0	85.2	105.0
10.3	26.9	7.8	45.0	366.0	84.5	105.0
9.3	38.4	7.1	54.8	407.5	84.0	105.0
8.6	47.1	6.5	62.2	427.5	83.4	104.7
8.9	122.1	6.3	137.3	467.5	83.0	104.5

Air cushion,at cutting out point, 370.5 gallons.

Air cushion, at cutting in point, 406.5 gallons.

Cutting in pressure, 90.5 pounds.

Cutting out pressure, 105.5 pounds.


Lbs Pressure.
110
105
100
95
90
85
80
120
80
40
Seconds.
a
b
c
d
e
a – Max. Pressure.
b – Min. Pressure.
c – Total Period.
d – Resting Period.
e – Running Period.
0
50
100
150
200
250
300
350
400
450
Gallons Per Minute.

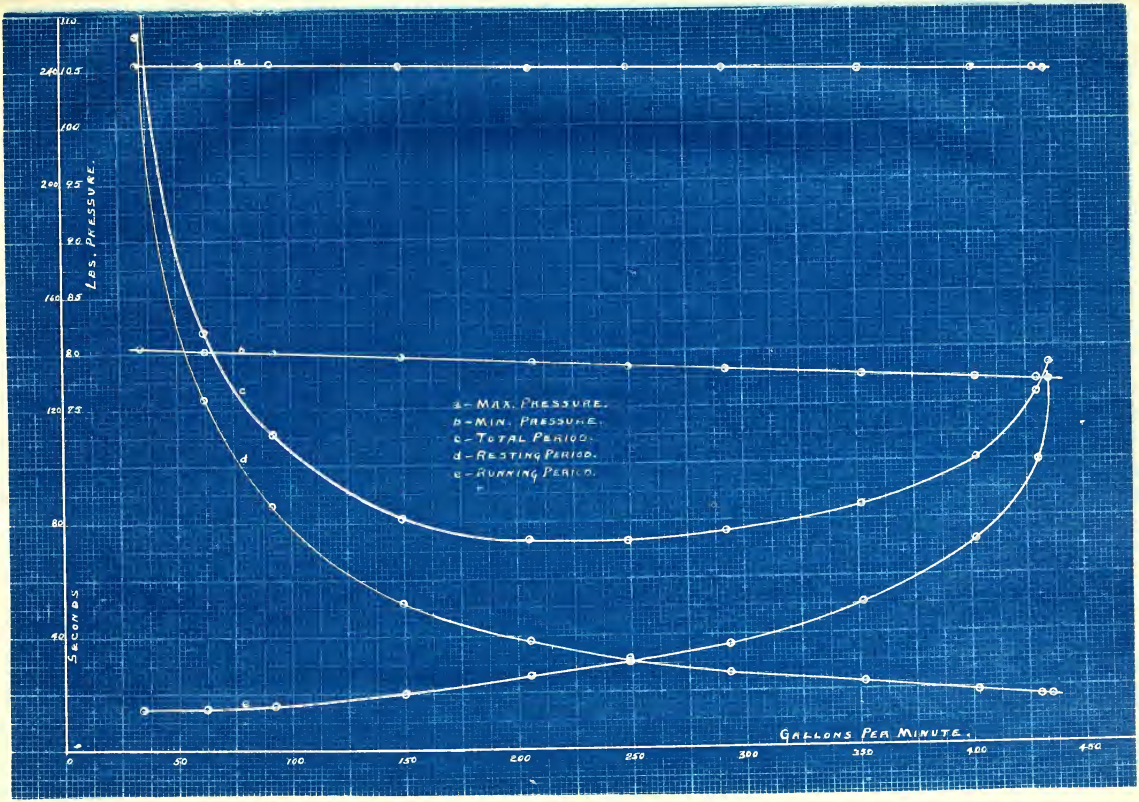
Acc. Period.	Running Period.	Resting Period.	Total Period.	Gallons per Minute.	Minimum Pressure.	Maximum Pressure.
10.3	13.9	250.6	274.8	34.3	80.5	105.5
9.7	14.6	122.9	147.2	62.5	80.2	105.5
9.7	16.1	86.1	111.9	92.0	80.0	105.5
9.2	19.7	51.5	80.4	149.0	79.5	105.2
9.8	25.6	38.9	74.3	206.0	79.0	105.0
9.7	30.6	32.7	73.0	249.0	78.5	105.0
9.5	40.4	26.4	76.3	293.5	78.5	105.0
10.0	51.3	23.2	84.5	352.5	77.5	104.5
9.3	72.2	18.5	100.0	402.5	77.3	104.5
9.0	99.0	17.4	125.4	430.0	77.1	104.5
9.1	127.2	17.3	153.6	435.0	77.0	104.5

Air cushion, at cutting out point, 604 gallons.

Air cushion, at cutting in point, 727 gallons.

Cutting in pressure, 80.5 pounds.

Cutting out pressure, 105 pounds.


LBS. PRESSURE.
SECONDS
GALLONS PER MINUTE.
a
b
c
d
e
a-MAX. PRESSURE.
b-MIN. PRESSURE.
c-TOTAL PERIOD.
d-RESTING PERIOD.
e-RUNNING PERIOD.
110
100
95
90
85
80
75
240
200
160
120
80
40
0
50
100
150
200
250
300
350
400
450

cutting-in and cutting-out pressures of the system; fifth, the discharge of the pump at full speed and average head.

The minimum total period is of importance because as the total period increases, the amount of water necessary to supply the system while the pump is out of service, also increases. The acceleration period has to be taken into account because the full-speed period is less than the running period by a time equal to the acceleration period; the pump therefore supplying less water during the running period than during a full-speed period of the same length. When the controller starts the pump, the demand upon the system is greater than the pump alone can supply, consequently the tank has to furnish a part of it till the pump attains sufficient speed to furnish all. Since the pump does not come to full speed instantly, the pressure in the tank will drop below the cutting-in point. This decrease in pressure will vary with the discharge from the system and will therefore reach a maximum when the demand upon the system is just enough below the maximum capacity of the pump to allow the system to work automatically. The importance of the third consideration in therefore evident, for with small discharges the system would perhaps work all right even if this factor were not taken care of, yet with heavy discharges a part or all of the air cushion might be discharged from the tank, thus destroying the end for which the tank is installed. The fourth consideration cannot be neglected because the volume of water necessary to raise the pressure from cutting-in to the cutting-out point has to be supplied by the pump and discharged from the system during the allowable controller period. The

capacity of the pump is of importance because the time necessary to restore pressure varies inversely with it.

In all calculations the following symbols will be used:-

e = full speed period.

e' = minimum allowable total period of the controller.

e" = " acceleration period of the controller.

G = capacity of the pump, while discharging against the average working head, at full speed.

a = absolute cutting-out pressure.

b = " " in " .

X' = air cushion at cutting-in point, in gallons.

X = " " " minimum pressure, " " .

V = amount of water necessary to raise the pressure from cutting-in to cutting-out point, gallons.

It was shown in the first part of this discussion that the controller operates most frequently when the demand upon the system equals one-half the pump capacity. This being the case, it is obvious that all calculations involving the total period of the controller should be made with such a discharge. It has also been shown that the pump delivers to the tank during acceleration period, only one-fourth the amount which it would deliver in the same time, if running at full speed. Thus three-quarters of the acceleration period of the pump is, in reality, lost so far as performing work is concerned. The work done on the tank by the pump, if it could be brought to full speed instantly, is the same as what would be done in the total period minus three-fourths of the acceleration period. We will call the frequency minus three-fourths

the acceleration period, the equivalent period. Therefore, the equivalent period equals

$$e' - 3/4\ e'' = \frac{4e' - 3e''}{4} \text{ seconds.}$$

The pump comes to rest almost instantly, therefore the period of rest or the period of maximum tank discharge, has no acceleration period.

The period of rest = one-half the equivalent period

$$= \frac{4e' - 3e''}{8} \text{ seconds.}$$

The period of run = one-half the equivalent period plus three-fourths the acceleration period.

$$= \frac{4e' + 3e''}{8} \text{ seconds.}$$

The full speed period of the pump is the period of run minus the acceleration period. Therefore

$$e = \frac{4e' + 3e''}{8} - e'' = \frac{4e' - 5e''}{8} \text{ seconds.}$$

The equivalent running period is equal to the full-speed period plus one-fourth the acceleration period, since the pump delivers one-fourth the amount of water to the tank during acceleration period that it would during a full speed period of the same length. The equivalent running period, therefore equals

$$e + e''/4 = \frac{4e' - 5e''}{8} + e''/4 = \frac{4e' - 3e''}{8} \text{ seconds.}$$

Since the pump delivers G gallons per minute, it will deliver G/60 gallons per second. Since the demand upon the system equals one-half the pump discharge, the pump will deliver one-half its discharge throughout the equivalent running period. The water delivered during equivalent running period is

$$V = 1/2 \times G/60 \times \frac{4\theta' - 3\theta''}{8} = \frac{G(4\theta' - 3\theta'')}{960} \text{ gallons.}$$

The volume of a gas varies inversely with its absolute pressure, or $PV = P'V'$. (Boyle's Law). Therefore

$$bX' = a(X - V) \text{ or } X' = \frac{aV}{a - b}$$

The expression $\frac{aV}{a - b}$ does not take into account the loss in volume of water in the tank and the consequent drop in pressure due to heavy discharges. Since it represents the amount of water necessary to raise the pressure from cutting-in point to cutting-out point, it is constant for all discharges. If now we take into account the greatest amount of water which the tank can loose during the acceleration period, we will have provided for the greatest possible drain upon the system. The greatest drop in pressure, during acceleration period, will take place when the discharge from the system is the greatest which the system can stand and still work automatically.

The maximum pump discharge per second = G/60 gallons. The pump will deliver half the amount during acceleration period which it would during a full speed period of the same length, therefore the tank will deliver the other half or $\frac{G\theta''}{120}$ gallons during the acceleration period.

With a discharge equal to the pump capacity, the system will not work automatically, owing to the pump's inability to raise the pressure in the tank from the cutting-in point to the cutting-out. From our data, we decided that 90% of G was the maximum discharge that could be used. The water lost during acceleration period therefore equals $\frac{.9G\theta''}{120}$ gallons.

The air cushion should be at least as large as the amount of water lost during one complete cycle, therefore

$$X = \frac{aV}{a - b} + \frac{.9Ge''}{120}$$

Substituting for V

$$X = \frac{aG(4e' - 3e'')}{960(a - b)} + \frac{.9Ge''}{120}$$

It will be seen that our formula is based upon the actual cutting-in pressure, rather than upon the minimum point to which the pressure in the tank drops. In some cases the maximum and minimum pressures desired will be given instead of the cutting-in and cutting-out pressures. In such instances, the cutting-in points would have to be assumed till an air cushion was found which would allow the proper drop in pressure. After determining the air cushion for any given cutting-in pressure, the minimum pressure could be determined as follows:- The volume of air at cutting-in point can be determined from the expression $\frac{aG(4e' - 3e'')}{960(a - b)}$; the decrease in volume can be determinèd from the expression $\frac{.9Ge''}{120}$. The minimum pressure will bear the same ratio to the cutting-in pressure that the volume at the cutting-in point bears to the total air cushion.

As a check upon the formula, the pressures and periods determined in the tests on the laboratory equipment, were substituted in it. The acceleration and total periods were obtained from the log sheets, also the cutting-in and cutting-out pressures; G was taken at 500 gallons per minute. The results of the substitutions showed air cushions of 830, 1015, 750, 665, 460, and 685 gallons, while the actual cushions used with those periods were 1040, 1252, 854, 611, 407, and 727 gallons respectively. From a comparison of the results, it is seen that the formula does not give as large air cushions in case of the larger volumes, while with the smaller ones, the

theoretical cushion is the larger.

The comparison would go to show that the formula connot be depended upon within 20%, but in the minds of the writers, more actual comparisons should be made and upon different sized pumps, before any definite conclusions were expressed. Further tests could not be made, however, because of insufficient time.

The expression, $\frac{aG(4e' - 3e'')}{960(a - b)} + \frac{.9Ge''}{120}$, represents the maximum air cushion necessary for a given installation, since it is the cushion at minimum pressure. The tank should be made slightly larger than the required maximum air cushion, to take care of any errors in controller periods, pump capacity, or controlling pressures. For example, if the capacity of the tank was greater than that credited it, the tank should be larger than the formula would show. Then again, if the cutting-in and cutting-out pressures were increased, while their difference remained the same, a larger air cushion would be required. The exact amount of excess to allow could be left to the engineer in charge of the installation, but the writers suggest that about 10% be allowed.

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Examiner

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